

WHAT IS CLAIMED IS:

1           1.     A class AB output circuit having an input terminal and an output terminal,  
2     comprising:

3                   (a)     a P-channel first output transistor having a source coupled to a first supply  
4     voltage, a drain coupled to the output terminal, and a gate coupled to respond to an input signal  
5     on the input terminal, and an N-channel second output transistor having a drain coupled to the  
6     output terminal, a source coupled to a second supply voltage, and a gate coupled to respond to  
7     the input signal;

8                   (b)     a first N-channel transistor having a drain coupled to a gate of the first  
9     output transistor and also coupled to the first supply voltage by means of a first current source  
10    and a source coupled to the second supply voltage by means of a second current source;

11                  (c)     a first diode-connected N-channel transistor, a second diode-connected N-  
12    channel transistor, and a first voltage level shifting circuit coupled in series between the second  
13    supply voltage and a gate of the first N-channel transistor, and a current source coupled between  
14    the first supply voltage and the gate of the first N-channel transistor; and

15                  (d)     a second voltage level shifting circuit coupled between the gate of the  
16    second output transistor and the source of the first N-channel transistor.

1           2.       The class AB output circuit of claim 1 wherein the first voltage level shifting  
2 circuit has a first terminal coupled to a gate and drain of the first diode-connected N-channel  
3 transistor and a second terminal coupled to a source of the second diode-connected N-channel  
4 transistor, a gate and drain of the second diode-connected N-channel transistor being coupled to  
5 the gate of the first N-channel transistor, a source of the first diode-connected N-channel  
6 transistor being coupled to the second supply voltage conductor.

1           3.       The class AB output stage of claim 2 wherein the first terminal of the first voltage  
2 level shifting circuit is connected directly to the gate and drain of the first diode-connected N-  
3 channel transistor.

1           4.       The class AB output stage of claim 3 wherein the first terminal of the first voltage  
2 level shifting circuit is indirectly coupled to the gate and drain of the first diode-connected N-  
3 channel transistor by means of an operational amplifier having a first input connected to the gate  
4 and drain of the first diode-connected N-channel transistor and a second input connected to the  
5 first terminal of the first voltage level shifting circuit and an output coupled to provide feedback  
6 control of the voltage of the second terminal of the first voltage level shifting circuit.

1            5.        The class AB output circuit of claim 2 wherein the first supply voltage is positive  
2 relative to the second supply voltage, and wherein the first and second terminals of the first  
3 voltage level shifting circuit are (+) and (-) terminals, respectively, and wherein a (+) terminal of  
4 the second voltage level shifting circuit is coupled to the gate of the second output transistor and  
5 a (-) terminal of the second voltage shifting circuit is coupled to the source of the first N-channel  
6 transistor.

1            6.        The class AB output circuit of claim 1 wherein the input signal is coupled directly  
2 to the gate of the second output transistor.

1            7.        The class AB output circuit of claim 1 wherein the input signal is coupled  
2 indirectly to the gate of the second output transistor.

1            8.        A class AB output circuit having an input terminal and an output terminal,

2 comprising:

3 (a) a P-channel first output transistor having a source coupled to a first supply  
4 voltage and a drain coupled to the output terminal, and an N-channel second output transistor  
5 having a drain coupled to the output terminal and a source coupled to a second supply voltage;

6 (b) a first P-channel transistor having a source coupled to the output terminal  
7 and a gate coupled to the input terminal;

8 (c) a first N-channel transistor having a drain coupled to a gate of the first  
9 output transistor and also coupled to the first supply voltage by means of a first resistor and a  
10 source coupled to the second supply voltage by means of a second current source;

11 (d) a first diode-connected N-channel transistor having a source connected to  
12 the second supply voltage;

13 (e) a first voltage level shifting circuit having a (+) terminal coupled to a gate  
14 and drain of the first diode-connected N-channel transistor;

15 (f) a second diode-connected N-channel transistor having a source connected  
16 to a (-) terminal of the first voltage level shifting circuit; and

17                   (g)     a second voltage shifting circuit having a (-) terminal coupled to the gate  
18 of the second output transistor and a drain of the first P-channel transistor and a (+) terminal  
19 coupled to the source of the first N-channel transistor.

1               9.     The class AB output circuit of claim 8 wherein the first voltage level shifting  
2 circuit includes an operational amplifier having a (-) input coupled to the gate and drain of the  
3 first diode-connected N-channel transistor and a (+) input coupled to the source of the second  
4 diode-connected N-channel transistor.

1               10.    The class AB output circuit of claim 9 wherein the (+) input of the operational  
2 amplifier is coupled to the source of the second diode-connected N-channel transistor by means  
3 of a first level shifting resistor having a first terminal coupled to the (+) input of the operational  
4 amplifier and a second terminal coupled to the source of the second diode-connected N-channel  
5 transistor.

1            11.     The class AB output circuit of claim 10 wherein the second voltage level shifting  
2 circuit includes a second resistor having a first terminal coupled to the gate of the second output  
3 transistor and a second terminal coupled to the source of the first N-channel transistor.

1            12.     The class AB output circuit of claim 11 including a second N-channel transistor  
2 having a source coupled to the second supply voltage, a drain coupled to the second terminal of  
3 the first voltage level shifting resistor, and a gate coupled to an output of the operational  
4 amplifier.

1            13.     The class AB output circuit of claim 12 including a third N-channel transistor  
2 having a source coupled to the second supply voltage, a drain coupled to the second terminal of  
3 the second voltage level shifting resistor, and a gate coupled to an output of the operational  
4 amplifier.

1           14.     The class AB output circuit of claim 11 wherein the resistance of the second  
2 resistor tracks the resistance of the first resistor with respect to temperature.

1           15.     The class AB output circuit of claim 13 wherein the output of the operational  
2 amplifier performs the function of setting the voltage of the first terminal of the first resistor to  
3 be equal to the voltage of the gate and drain of the first diode-connected transistor.

1           16.     A method of operating a class AB output circuit at reduced power supply voltage  
2 levels, the class AB output circuit including

3                   an input terminal and an output terminal,

4                   a P-channel first output transistor having a source coupled to a first supply  
5 voltage, a drain coupled to the output terminal, and a gate coupled to respond to an input signal  
6 on the input terminal, and an N-channel second output transistor having a drain coupled to the  
7 output terminal, a source coupled to a second supply voltage, and a gate coupled to respond to  
8 the input signal, a first N-channel transistor having a drain coupled to a gate of the first output  
9 transistor and also coupled to the first supply voltage by means of a first current source and a

source coupled to the second supply voltage by means of a second current source,

a first diode-connected N-channel transistor and a second diode-connected N-channel transistor coupled in a series relationship between the second supply voltage and a gate of the first N-channel transistor, and a current source coupled between the first supply voltage and the gate of the first N-channel transistor,

the method comprising:

(a) shifting a first voltage level on the gate and drain of the first diode-connected N-channel transistor by a first predetermined amount to a first lower level and applying the first lower level to the source of the second diode-connected N-channel transistor; and

(b) shifting a second voltage level on the gate of the second output transistor by a second predetermined amount to a second lower level and applying the second lower level to the source of the first N-channel transistor.

17. A class AB output circuit for operation at reduced power supply voltage levels, comprising:



an input terminal and an output terminal,

a P-channel first output transistor having a source coupled to a first supply voltage, a drain coupled to the output terminal, and a gate coupled to respond to an input signal on the input terminal, and an N-channel second output transistor having a drain coupled to the output terminal, a source coupled to a second supply voltage, and a gate coupled to respond to the input signal, a first N-channel transistor having a drain coupled to a gate of the first output transistor and also coupled to the first supply voltage by means of a first current source and a source coupled to the second supply voltage by means of a second current source;

a first diode-connected N-channel transistor and a second diode-connected N-channel transistor coupled in a series relationship between the second supply voltage and a gate of the first N-channel transistor, and a current source coupled between the first supply voltage and the gate of the first N-channel transistor;

means for shifting a first voltage level on the gate and drain of the first diode-connected N-channel transistor by a first predetermined amount to a first lower level and applying the first lower level to the source of the second diode-connected N-channel transistor; and

means for shifting a second voltage level on the gate of the second output transistor by a second predetermined amount to a second lower level and applying the second

21 lower level to the source of the first N-channel transistor.

1 18. A voltage reference circuit comprising:

2 (a) a class AB output circuit including

3 i. a P-channel first output transistor having a source coupled to a first  
4 supply voltage, a drain coupled to the output terminal, and a gate coupled to respond to an input  
5 signal on the input terminal, and an N-channel second output transistor having a drain coupled to  
6 the output terminal, a source coupled to a second supply voltage, and a gate coupled to respond  
7 to the input signal,

8 ii. a first N-channel transistor having a drain coupled to a gate of the first  
9 output transistor and also coupled to the first supply voltage by means of a first current source  
10 and a source coupled to the second supply voltage by means of a second current source,

11 iii. a first diode-connected N-channel transistor, a second diode-connected  
12 N-channel transistor, and a first voltage level shifting circuit coupled in series between the  
13 second supply voltage and a gate of the first N-channel transistor, and a current source coupled  
14 between the first supply voltage and the gate of the first N-channel transistor, and

15 iv. a second voltage level shifting circuit coupled between the gate of the  
16 second output transistor and the source of the first N-channel transistor;

17                   (b)     a bandgap reference voltage circuit; and

18                   (c)     a feedback amplifier including a first input coupled to an output of the  
19     bandgap reference voltage circuit, a second input coupled to receive a feedback signal produced  
20     in response to an output voltage on the output terminal, and an output coupled to produce the  
21     input signal on the input terminal.

1                19.     The reference circuit of claim 18 including a feedback circuit including a first  
2     feedback resistor and a second feedback resistor coupled in series between the output terminal  
3     and the second supply voltage, the feedback signal being produced at a junction between the first  
4     and second feedback resistors.